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Growth Impact of the North Kaibab Pandora Moth Outbreak

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Tree mortality and growth were examined in defoliated, insecticide treated, and undefoliated stands in the pandora moth outbreak area on the Kaibab National Forest. Tree mortality was less than 1%. Radial and basal area growth were significantly different among areas in trees ⩾ 14 inches d.b.h. and increased significantly in the undefoliated area, while rates in the defoliated and treated areas remained unchanged. Defoliation loss was estimated at least 11 f.b.m. per acre per year.

Keywords: Pandora moth, *Coloradia pandora,* growth impact, ponderosa pine

Introduction

When the pandora moth (*Coloradia pandora* Blake) population became evident in ponderosa pine (*Pinus ponderosa* Lawson) stands, west of Jacob Lake, Arizona in 1979, forest managers and pest management specialists were concerned about the long-term impacts of the outbreak. Most previously documented outbreaks (Patterson 1929, Wygant 1941) killed trees, although the mortality was significantly less than the extent of the infestation. Within defoliated stands in several infestations, tree mortality solely attributable to defoliation was less than that caused by the coincidental increase in bark beetle-killed trees.

Growth loss appeared to be more significant in the earlier outbreaks. Patterson (1929) notes an 80% reduction in annual growth in some trees but considers the estimation of total growth loss to be difficult. Wygant (1941) considers three classes of injury, with increment loss an important, undocumented aspect of the Colorado infestation.

Growth loss appeared to be the most significant impact of the North Kaibab outbreak, because tree mortality directly attributable to either severe defoliation or the simultaneous infestations of bark beetles was rare. After the 1981 defoliation, Bennett and Andrews (1983) evaluated tree mortality and growth loss attributable to the two previous defoliations. They found negligible mortality, a 25% basal area growth loss in stands defoliated twice previously, and greater growth reduction in dwarf mistletoe infested trees than in noninfested trees. A subsequent study determined tree mortality was greater than average in several stands with high incidences of dwarf mistletoe (Wagner and Mathiasen 1985).

Since the initial survey by Bennett and Andrews, the outbreak has collapsed. Defoliation averaged 20% to 30% in 1983, with only pockets of severe or complete defoliation reminiscent of prior defoliations. In 1985, no visible defoliation was discernible in previously defoliated stands. With the collapse of the outbreak, this note reports the results of a 1985 survey to determine mortality and growth loss attributed to this outbreak.

Methods

From aerial survey maps of the 1979, 1981, and 1983 defoliation, three areas were generally delineated in relation to the pandora moth outbreak: (1) defoliated area—stands completely defoliated in 1979 and 1981, and partially defoliated in 1983; (2) treatment area—stands in the vicinity of Jacob Lake Inn which received aerial applications of acephate in 1981 and 1983, and would have been severely defoliated in 1981 if not treated; and (3) undefoliated area—stands where no visible defoliation was evident in 1979, 1981, and 1983, the years when severe defoliation occurred elsewhere.

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In each area, 10 starting points were systematically located during September 17–19, 1985. Each location was adjacent to a road and served as the starting point for a series of five variable radius plots, which were established at 5-chain intervals along a compass line beginning at the starting point. A prism of 20 square feet per acre basal area factor was used at each centerpoint to determine trees to be tallied. All tallied trees were measured for diameter at breast height to the nearest 0.1 inch.

Two increment cores were taken from opposite sides of the first three trees on each plot, and total height was measured to the nearest foot on these trees. The cores were taken to the laboratory and were frozen until they could be measured. When measured, the width of each ring for the last 15 years was measured to the nearest 0.001 inch.

Mean total radial growth for each area during the preoutbreak period (years 8–14) was compared against the respective mean total radial growth during the outbreak period (years 1–7) in a paired sample t-test, α = 0.05. Because diameters ranged from 5.1 to 37.8 inches and it was of interest to determine whether defoliation affected large trees differently than small trees, the range in diameters was arbitrarily divided into two classes—trees $<$14 inches d.b.h. and trees $\geqslant$ 14 inches d.b.h. The radial growth in each class for each area was then subjected to paired t-test analysis testing for significant variation between pre- and dureoutbreak growth, α = 0.05. Basal area growth for the same periods was tested for each area in the same manner.

Because plot basal area varied, total radial growth for years 1979–85 was tested for significant differences among areas using analysis of covariance, with total radial growth for years 1972–78 and plot basal area as covariates, α = 0.05. Similarly, basal area growth was computed for each plot, and mean basal area growth for each area was compared, using the same analysis of covariance for the same time period.

To determine annual growth in board feet per tree for each area, diameter, radial growth, and height measurements for the cored trees only were used in volume equations for ponderosa pine developed by Hann and Bare (1978). The 1978 diameters were derived by subtracting radial growth measurements from the 1985 diameters. Past height was estimated using height-diameter curves constructed for each area.

Results and Discussion

Tree Mortality

Tree mortality was less than 1% in each of the three areas and was not significantly different among areas. A coincident increase in bark beetle infested trees also was not evident. Above average precipitation in 1981 may have mitigated the stress of defoliation and reduced the possibility of coincidental bark beetle infestation.

Radial Growth

When all diameters were analyzed together, radial growth significantly increased in the undefoliated area during the defoliation period but remained unchanged in both the defoliated and treated areas (table 1). Radial growth in trees $<$ 14 inches d.b.h. remained unchanged in all areas during the outbreak, while in the $\geqslant$ 14-inch d.b.h. class only trees in the defoliated area had unchanged growth rates. When mean radial growth during the outbreak was adjusted for plot basal area, growth for all diameters and for trees $<$ 14 inches d.b.h. were not significantly different among areas. While the adjusted mean radial growth for the defoliated and treated areas was not significantly different between growth periods, the growth trend decreased slightly in the defoliated area and increased slightly in the treated area.

Defoliation influenced the growth rate of larger trees ($\geqslant$ 14 inches) more than smaller trees ($<$ 14 inches). Most of the trees $\geqslant$ 14 inches d.b.h. had diameters greater than 20 inches and were adding barely discernible annual growth. Even though they were dominant, healthy trees, their physiological condition at this advanced age apparently inhibits them from recovering quickly from the defoliation, whereas smaller diameter trees ($<$ 14 inches) suffer temporarily reduced growth but resume the predefoliation rate of growth soon after defoliation. Some of the variation in growth of trees $<$ 14 inches in the defoliated area during the outbreak was attributed to variable stand density, which resulted from coincidental intermediate cutting. The cutting released some trees, allowing them to achieve the same growth rate as during the preoutbreak period. The effect of the cutting thus mitigated the effect of the defoliation and prohibited a precise estimate of growth loss.

Basal Area Growth

Basal area growth in all three areas followed essentially the same pattern as radial growth. For all diameters, unadjusted basal area growth in the undefoliated area increased significantly during the outbreak, while it remained unchanged in the defoliated and treated areas (table 2). Basal area growth in trees $<$ 14 inches d.b.h. was unchanged between preoutbreak and dureoutbreak in all three areas. For trees $\geqslant$ 14 inches d.b.h., basal area growth significantly increased during the outbreak in the undefoliated area but remained unchanged in the defoliated and treated areas. When mean basal area growth was adjusted for plot basal area, dureoutbreak growth in the undefoliated area was significantly greater (17%) than in the treated area and about 15% greater than in the defoliated area. However, differences in dureoutbreak growth rates among areas are less important than differences between pre- and dureoutbreak growth within each area because of the confounding effect of insecticide application in the treated area and silvicultural thinning operations in the defoliated area. Within areas, basal area growth in the undefoliated area increased 15%, while the treated area increased 9% and the defoliated area remained unchanged.

Table 1.—Pre- and dureoutbreak periodic radial growth (0.001 inch) by diameter class for the defoliated, treated, and undefoliated areas.

Diameter per area	Preoutbreak (1972-1978)	Dureoutbreak (1979-1985)	Difference	% change
	$\bar{x} \pm$ S.E.[1]			
All diameters				
Defoliated	178 ± 11a	186 ± 15a	+ 9	5
Treated	163 ± 13a	167 ± 17a	+ 4	2
Undefoliated	146 ± 12a	169 ± 11b	+ 23	16
<14 inches d.b.h.				
Defoliated	247 ± 30a	332 ± 75a	+ 84	34
Treated	188 ± 24a	199 ± 26a	+ 11	6
Undefoliated	221 ± 72a	236 ± 77a	+ 15	7
⩾14 inches d.b.h.				
Defoliated	158 ± 10a	158 ± 12a	0	0
Treated	155 ± 11a	143 ± 11b	-12	-8
Undefoliated	140 ± 10a	163 ± 11b	+ 23	16
All diameters[2]				
Defoliated	178 ± 11a	166 ± 11a	-12	-7
Treated	163 ± 13a	172 ± 11a	+ 9	5
Undefoliated	146 ± 12a	184 ± 11b	+ 38	26

[1]*Within the same row, means followed by the same letter are not significantly different, $\alpha = 0.05$.*
[2]*Mean growth during the outbreak adjusted for variation caused by plot basal area.*

Table 2.—Pre- and dureoutbreak periodic tree basal area growth (0.01 square foot) by diameter class for the defoliated, treated, and undefoliated areas.

Diameter per area	Preoutbreak (1972-1978)	Dureoutbreak (1979-1985)	Difference	% change
	$\bar{x} \pm$ S.E.[2]			
All diameters				
Defoliated	9.8 ± 0.8a	10.4 ± 1.0a	+ 0.6	6
Treated	8.6 ± 0.8a	8.6 ± 0.6a	0.0	0
Undefoliated	9.8 ± 0.8a	11.4 ± 0.8b	+ 1.6	16
<14 inches d.b.h.				
Defoliated	6.7 ± 1.3a	8.8 ± 1.8a	+ 2.1	31
Treated	5.7 ± 0.8a	6.1 ± 0.9a	+ 0.4	7
Undefoliated	5.1 ± 1.5a	5.8 ± 1.7a	+ 0.7	14
⩾14 inches d.b.h.				
Defoliated	10.7 ± 0.6a	11.1 ± 0.9a	0.4	4
Treated	10.1 ± 0.8a	9.7 ± 0.8a	–0.4	–4
Undefoliated	10.2 ± 0.8a	11.8 ± 0.8b	+ 1.6	16
All diameters[1]				
Defoliated	9.8 ± 0.8a	9.7 ± 0.5a	–0.1	–1
Treated	8.6 ± 0.8a	9.4 ± 0.5a	+ 0.8	9
Undefoliated	9.8 ± 0.8a	11.3 ± 0.5b	+ 1.5	15

[1]*Mean growth during the outbreak adjusted for variation caused by plot basal area.*
[2]*Within the same row, means followed by the same letter are not significantly different, $\alpha = 0.05$.*

The lesser growth in the treated area indicates "foliage protection" treatments maintained green foliage and mitigated growth loss. Some foliage loss was not prevented, because treatments were applied in early May and 25% to 50% of the defoliation may occur before treatment. Thus, even with 100% larval mortality immediately after treatment, some defoliation and growth reduction will occur. However, adjusted larval mortality ascribed to the treatment did not exceed 50% and further defoliation may have been allowed. Also, because some insecticides adversely affect photosynthesis (Kozlowski 1986), some growth reduction may be attributable to the treatments. In any case, the net treatment effect was a 9% saving in growth reduction.

Basal area growth in the defoliated area was influenced by silvicultural treatments initiated at the beginning of the outbreak. As explained in the radial growth section, growth after thinning may have been greater than if no thinning had occurred. This confounding also may explain why the 25% basal area reduction in the defoliated

area found by Bennett and Andrews (1983) was greater than the 15% found in this 1985 study.

Board Foot Volume (f.b.m.) Growth

Net volume growth per year on the average tree was 2.3, 1.8, and 2.9 f.b.m. for the defoliated, treated, and undefoliated areas, respectively (table 3). On a per acre basis, net growth was estimated at 114, 128, and 134 f.b.m. for each of the three areas, respectively. Because defoliation reduced growth 10% to 15% (tables 1 and 2), f.b.m. growth in the defoliated and treated areas should have been greater. If annual f.b.m. growth for the average tree in the defoliated area was 10% greater than that listed in table 3 (i.e., 2.53 f.b.m. rather than 2.3 f.b.m.), then annual f.b.m. growth per acre would be 125 f.b.m. If the 11 f.b.m. difference was sustained throughout the 1979 area of moderate and severe defoliation (5,120 acres) for the duration of the outbreak (6 years), then the estimated loss would be 337,920 f.b.m. Based on a $60 per 1,000 f.b.m. timber value from a concurrent timber sale, the estimated loss would be $20,275.

Table 3.—Basal foot volume growth for the average cored tree in the defoliated, treated, and undefoliated areas during the pandora moth outbreak.

	Defoliated	Treated	Undefoliated
f.b.m. growth—7 years	16.2	12.9	20.3
f.b.m. growth per year	2.3	1.8	2.9
f.b.m. growth per acre per year	114.0	128.0	134.0

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